A NEW TEST METHOD TO CHARACTERIZE SETTING/SAG TENDENCIES OF DRILLING FLUIDS USED IN EXTENDED REACH DRILLING

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ABSTRACT

Extended reach drilling (ERD) is presenting a new problem with drilling fluids. In high angle holes, weighting materials can settle from drilling fluids and collect on the bottom of the hole. With some geometries and fluid conditions, the settled weighting material is mobile and "sags" downhole. Standard test methods to characterize the suspension properties are inadequate for fluids used in ERD.

A high angle sag test (HAST) device is presented which characterizes the "sag" signature of a fluid. The HAST device continuously measures the movement of the center of mass of a test fluid at temperatures to 300° F and deviation angles from 20° to 90°. Six tests can be performed simultaneously at various deviation angles. A computer-based data acquisition system collects data periodically and provides for curve fitting and integration. The integrated change in center of mass versus time function yields a single number which is characterized as the Sag Coefficient (SC).

Presently, viscosity parameters are prescribed to minimize sag/settling problems in ERD. The "sag" signature and sag coefficient obtained with the HAST device indicate that viscosity parameters are an unreliable measure for predicting the "sag" performance for fluids used in ERD. With the new insight gained with the HAST device, the "sag" problem can be addressed more effectively.

NOMENCLATURE

PV - Plastic Viscosity, centipoise
YP - Yield Point, lb/100 ft^2
SC - Sag Coefficient
SS - Sag Signature
A - Constant in the SS function
B - Constant in the SS function
X_{cmi} - Initial location of center of mass of the test fluid
X_{cmf} - Final location of central of mass of the test fluid
X_{cm} - Linear displacement of center of mass, $X_{cmf} - X_{cmi} = X_{cm}$
t - Time
ϕ - Deviation Angle
ppg - Pounds per Gallon

INTRODUCTION

Recently, a new area of interest in drilling has been the use of directional drilling to enhance well productivity or platform efficiency or both. High Angle Drilling (HAD) is now being used to enter payzones at high angles, often near horizontal, to provide better reservoir drainage and hence higher productivity. Extended reach drilling (ERD) is being employed to drill multiple targets off of one pad or platform, eliminating the need for moving the rig or platform, and generally reducing the overall environmental impact. With this increase in directional drilling or extended reach drilling, new problems with drilling fluids are occurring. When circulation of the drilling fluid is stopped for extended periods, the fluid column can develop sections with density discontinuities or heavy spots. One theory suggests that weighting materials and solids are settling on the bottom side of the hole. With some geometries and fluid chemistry, these discontinuities are mobile and can move or sag downhole, collecting in localized areas. The localized collection of solids is evidenced by the density variations experienced when circulation is resumed. Serious problems, such as stuck pipe and extreme recirculation pressures, can result if the sagging is severe. The problem seems to be most pronounced with low viscosity oil muds.

The observation of this phenomenon is not something new. It was first reported in 1920 by A.E. Boycott that if a suspension is left to stand in a narrow tube, the particles sediment much faster if the tube is inclined than if the tube is vertical.[1] Boycott observed this for the sedimentation of blood corpuscles, but it has found more general application as a solids separation technique. It has been studied in considerable detail in this regard.[2-5]

Our observations for drilling fluids show an important difference from most of the published work on sedimentation in tilted vessels. The sedimentation studies identify a layer of particle-free or clear liquid above a layer of concentrated slurry, and attempt to model the flow of these two layers with respect to each other. The drilling fluids we have studied frequently form a particle-free layer and a turbid layer of colloidal suspension over a concentrated slurry of weight material. Furthermore, with the proper fluid formulation we can greatly reduce the extent to which this effect occurs.

An instrument has been built to characterize the movement or sag of the solids in a drilling fluid. This instrument is referred to as the HAST device or high angle sag test device (patent pending). In the HAST device a small sample of fluid is placed in a tube at the desired deviation angle. With time the solids can settle/sag simulating the effect that is observed in the field. As the solids settle/sag the center of mass of the test fluid moves. Characterizing and measuring the fluid's center of mass movement is the basis of the HAST device. The center of mass versus time function (sag signature, SS) and the integrated sag signature function (sag coefficient, SC) are measures of the sag tendency of the fluid. These are sensitive measures of the fluid's settling/sag property. Small additions of products to the test fluid can have a significant effect on the SS and SC. Interestingly, there is minimal correlation of the SS and SC to the usual viscosity parameters used to characterize drilling fluids.

Historically, viscosity parameters such a PV, YP, 10-second gel, and 10-minute gel have been used to predict the settling and sag tendencies of drilling fluids. Recently, low shear rate rheological measurements have been used. Data from the HAST device indicate classical rheological measurements are unreliable to predict or treat drilling fluids to minimize settling and "sag."

EQUIPMENT AND TEST PROCEDURE

The major components and the fundamental method of the HAST device are shown in Figure 1. An oven (a) is provided with the HAST device which permits testing to 300° F (149° C). In the figure, one test cell, (b) is shown in the oven; the actual device has six cells. Each test cell is suspended from a sensor assembly, (c) outside the oven. The signal from each sensor is amplified and filtered. Signals from each sensor are continuously monitored by the data acquisition system. Output from each sensor is displayed on a computer monitor in strip-chart fashion. In normal operation, data from each channel is logged every ten minutes for twenty hour tests. Also connected to the sensor is a counterbalance (d). The counterbalance effectively applies an equal but opposite moment to the sensor as the mass of the test cell. The hardware which connects the test cell to the sensor allows measurements to be made at deviation angles, ϕ, from 20° to 90°. As a test proceeds, the center of mass of the fluid volume changes due to solids movement, causing a change in the measured moment. In the figure the initial mass center of the test fluid is labeled X_{cmi}. The mass center with solids movement is labeled X_{cmf}. The distance between X_{cmi} and X_{cmf} is the change in center of mass, X_{cm}. The moment change is converted to the change in the center of mass, with the known fluid density, volume and deviation angle.

Inside each test cell is a glass tube, (e), filled with 170 cc of test fluid. A piston, (f), with an axial vent hole, (g), is pressed in the tube until all air is excluded and then sealed. The test tube assembly is placed inside the test cell and pressurized with 100 psi (689.7 kPa) nitrogen through the valve assembly, (h). The piston isolates the test fluid from the pressurizing gas and moves freely with thermal expansion of the fluid.

After the test cell is placed in the oven, usually at test temperature, the fluid in the test cell begins to heat up. With increasing temperature, the center of mass of the fluid moves opposite the direction sag would occur. Once thermal equilibrium is reached, the fluid volume becomes constant and the usable data is collected. At this time in the test, an inflection point can be observed in the SS curve. The initial non-steady state data are not used to describe the SS or SC because of difficulties determining what center of mass change is due to sag and what is due to thermal non-equilibrium.

The change in center of mass versus time data obtained with the HAST device fit a function of the form:

$$X_{cm}(t) = A*t/(B+t) \qquad \text{(mm)}$$

Data is curve fit to this function using the software package GRAPH-PAD and is called the SS. Typically, the function fits the data with correlation coefficients greater than 0.95. Integrating this function with respect to time yields a single number, SC, which is indicative of the total sag that occurred during any given test. Thus, the SC is the following integral:

$$SC = \int_{t=0.0\text{ min.}}^{t=1200\text{ min.}} X_{cm}(t)dt \qquad \text{(mm min.)}$$

The SC has upper and lower bounds due to the geometry and finite volume of the test device. If no sag or movement of the fluid solids is observed, the SC is equal to zero. For drilling applications, where fluids are designed not to settle/sag, the ideal sag coefficient is zero. It is the relative difference from the ideal that is of interest.

RESULTS OF INVESTIGATION

Until now attempts to minimize sag have generally centered around controlling the yield point or gel strengths. This has led to mixed results in the field and serious questions about the ability to infer sag tendencies from conventional rheological properties. This study compared the 'classical' oilfield rheological properties of several drilling fluids to their sag tendencies as measured by the sag coefficient, SC. It was found that plastic viscosity, yield point, 10-second gel strength and 10-minute gel strength were all unreliable indicators of sag.

Figures 2-5 compare each of these rheological properties to the SC. The drilling fluids were 14 ppg invert emulsion oil muds with differing formulations. All tests were run at 250° F (121° C) and 45° deviation, and the rheological properties were measured at room temperature. It is clear from the graphs that there is only a minimal correlation

between any of the rheological properties and the sag coefficient. The best correlation coefficient for all cases was only 0.6.

The poor correlation between sag and conventional rheological properties was evident in two other studies that were conducted. One study looked at the relationship between the oil-to-water ratio, OWR, and the sag signatures, SS, for three 13.3 ppg (1.59 kg/L) mineral oil muds with similar additive concentrations. The 75/25 and 80/20 oil muds have almost the same yield points, gels and low shear readings, Table 1, but their sag signatures are very different. Figure 6 shows that the formulations with lower oil-to-water ratios exhibit significantly lower sag tendencies. This is a very important finding in terms of designing oil muds for high angle applications.

TABLE 1

EFFECT OF OIL/WATER RATIO

	A	B	C
Oil/Water Ratio	65/35	75/25	80/20
Plastic Viscosity	31	20	16
Yield Point lb/100 sq ft	15	7	7
10-sec. Gel, lb/100 sq ft	9	5	5
10-min. Gel, lb/100 sq ft	13	8	7
Readings at 3 and 6 rpm	9/10	4/5	3/4

Rheological properties at 120° F (49° C)

A second study investigating the application of suspension aids for reducing sag found a similar effect. Additions of 2, 4 and 6 ppb (5.71, 11.41, and 17.12 g/L) of a suspension agent to an 80/20 mineral oil mud produced dramatic reductions in the measured sag, but produced only very minimal changes in the conventional rheological properties. From Figure 7, it can be seen that the formulation with 6 ppb (17.12 g/L) of suspension agent exhibited more than 40% less sag than the formulation with 4 ppb (11.41 g/L) of the additive, but within experimental error their conventional rheological properties are identical, Table 2.

TABLE 2

EFFECT OF SUSPENSION AID

	A	B	C	D
Base Mud, bbl	1.0	1.0	1.0	1.0
Suspension Additive		2	4	6
Plastic Viscosity	21	22	25	26
Yield Point lb/100 sq ft	7	8	10	10
10-sec. Gel, lb/100 sq ft	5	6	8	7
10-min. Gel, lb/100 sq ft	8	10	12	11
Readings at 3 and 6 rpm	4/5	5/6	7/8	7/8

Rheological properties at 120° F (49° C)

The angle of deviation clearly plays an important role in the sag phenomenon. In the vertical situation the solids must settle through the entire fluid column, which is unlikely, and there are few if any wall effects. In the horizontal situation, the solids may settle very readily to the lower wall, but without an incline there is nothing to make the stratified fluid move. Somewhere between vertical and horizontal there is a region where sag occurs and is a potential problem. The HAST device makes it possible to study this effect and its relationship if any to properties of the fluid. This work is currently in progress. Figure 8 shows the effect of angle of inclination on the SS of a 16.7 ppg 85/15 OWR mineral oil mud. Angles of 25°, 45°, 65° and 85° studied. For this drilling fluid there is a critical angle between 65° and 85° where the sag diminishes substantially. The angle of onset appears to be between 0° and 25°. More important than the evidence of a critical angle is the evidence that at small deviation angles sag can occur and its magnitude is not dictated by the deviation angle.

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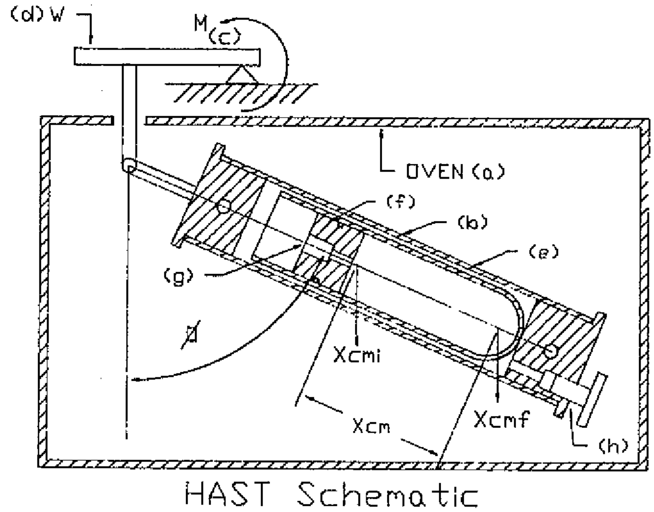

Figure 1. **HAST Schematic**

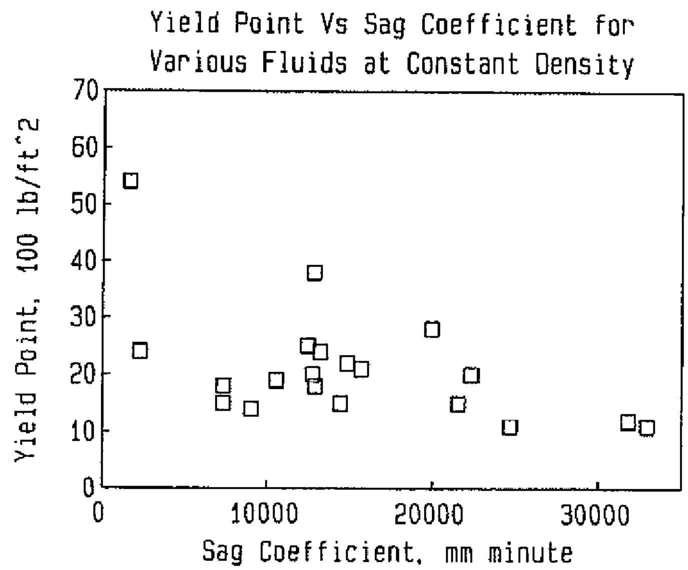

Figure 3. **Yield Point Vs. Sag Coefficient for Various Fluids at Constant Density**

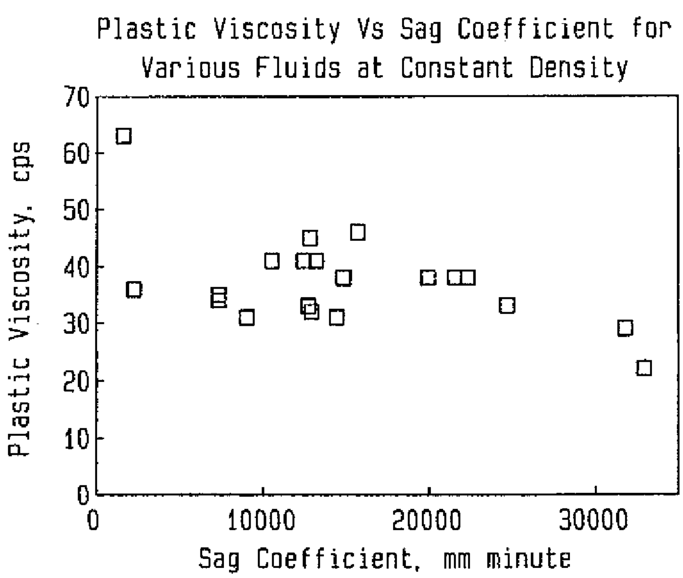

Figure 2. **Plastic Viscosity Vs. Sag Coefficient for Various Fluids at Constant Density**

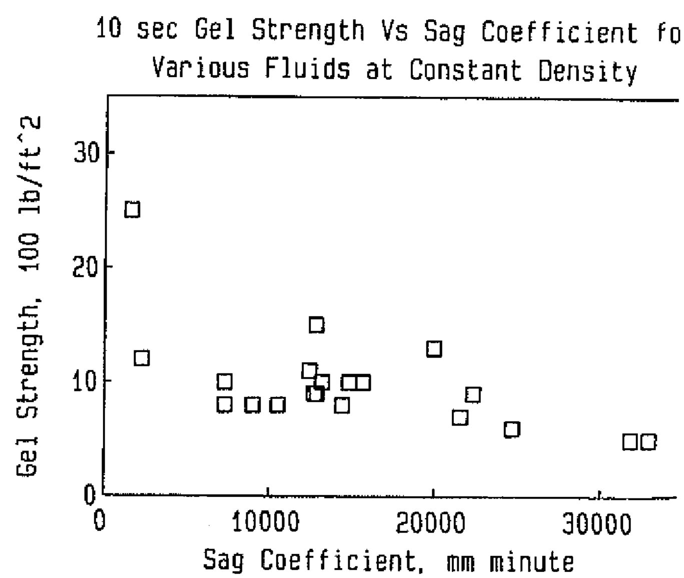

Figure 4. **10-Sec. Gel Strength Vs. Sag Coefficient for Various Fluids at Constant Density**

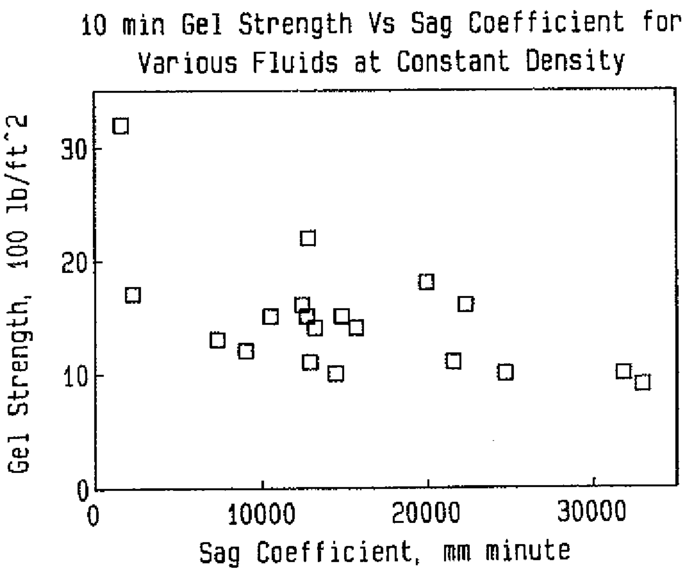

Figure 5. 10-Min. Gel Strength Vs. Sag Coefficient for Various Fluids at Constant Density

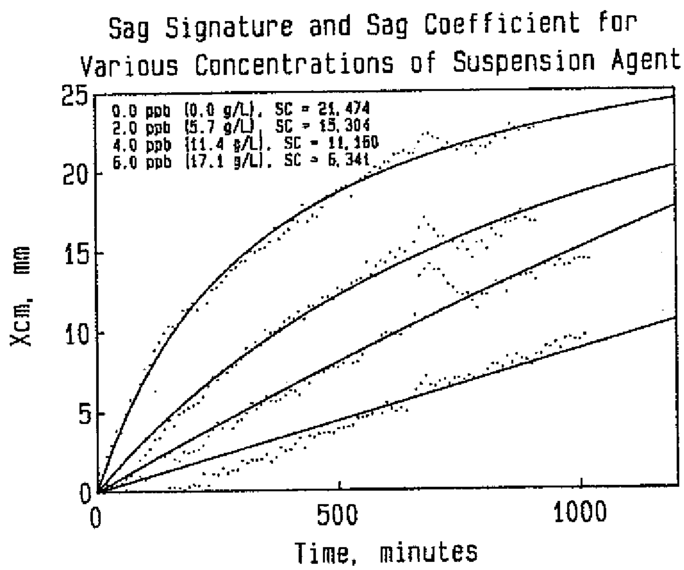

Figure 7. Sag Signature and Sag Coefficient for Various Concentrations of Suspension Agent

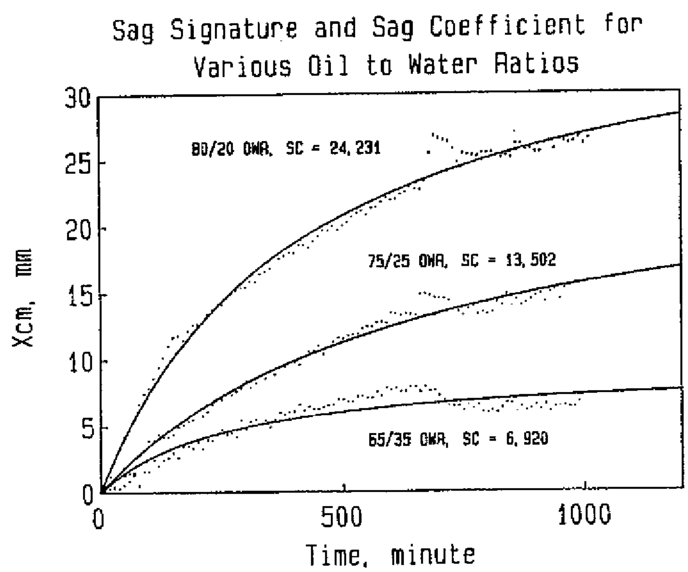

Figure 6. Sag Signature and Sag Coefficient for Various Oil-to-Water Ratios

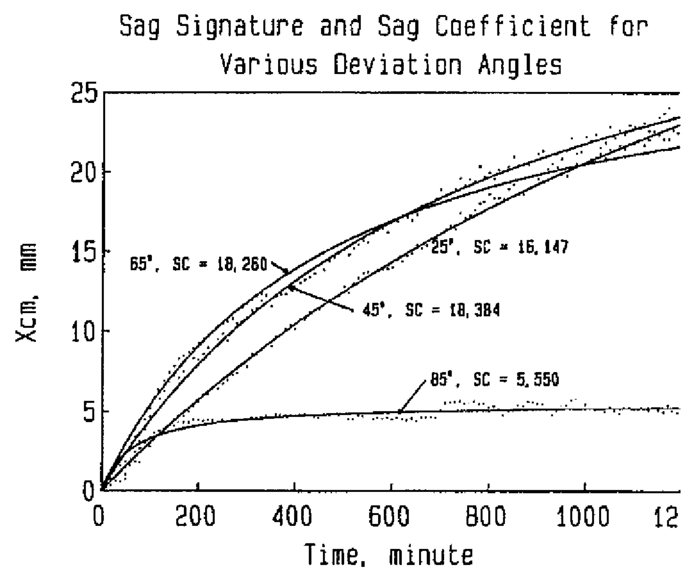

Figure 8. Sag Signature and Sag Coefficient for Various Deviation Angles